is not standardized, but is available in a half-dozen different types to meet varying operating conditions. The units, therefore, are suitable for the most difficult and abusive applications found in industrial and processing plants where conventional designs are likely to fail or to be inapplicable.

## DEAN EMERITUS GEORGE L. SULLIVAN

After forty-three years as teacher and administrator in the College of Engineering at the University of Santa Clara (California), Dr. George L. Sullivan was made Dean Emeritus on June 30, 1955. His career has been a long and illustrious one.

Holding degrees from the Universities of Nebraska and Colorado, he came to Santa Clara in 1912, and obtained his Ph.D. there in 1914. In the years that followed he had much to do with the platting and growth of the city of Santa Clara, devising its first master plan and its first zoning ordinance. Later he designed the city's first sewage-treatment plant and engineered its first street-paving jobs and storm-drainage projects.

In addition to these local activities, Dean Sullivan has been consultant on many outstanding projects, including the Golden Gate Bridge, and conservation dams built by the Santa Clara Valley Water Conservation District. He assisted in drawing up the first master sanitation plans for Santa Clara and Santa Cruz Counties.

A life member of the ASME, he is also chairman of the Society of Engineering Educators, belongs to the ASCE, and is a member of Sigma Xi and Sigma Tau. About Dean Sullivan, President Hauck of Santa Clara university has this to say:

> . . . Dean Sullivan . . . has made an outstanding contribution to the technological program of the State of California, to certain South American republics, and even to the Far East. What is more outstanding, he produced graduates with both practical realism and high social ideals. . . .

Summer 1955



# THERMOELECTRIC GENERATORS*

**Virgil E. Carrier, Epsilon Chapter**

If you could sell, at today's market value, all of the energy that falls on your back yard as free sunlight, you could retire for the rest of your life.

There are several ways in which man now uses the energy from the sun as is illustrated in figure 1. Life in any form would be impossible without this radiant energy which we call sunlight.

The tree, shown on the left, converts this solar energy into wood through the magic of photosynthesis and man burns the weed to recover a small part of the trapped energy. In days long before man was on the earth, forests captured the sunlight, then died and were buried beneath the earth's surface. Today man digs this "sunlight" out of the earth in the form of coal, or pumps it out as petroleum.

Also, the solar energy which falls on the oceans causes the water to evaporate into clouds. The clouds drift over the land and the water falls as rain, and man captures a very small part of the solar energy with hydroelectric dams.

All of these methods in which we use solar energy are fine and they are the methods provided for us by nature but they are all second hand and we know that we are paying dearly for these second hand dealings. The process of photosynthesis is only about 1/10 of one per cent efficient and when we burn the wood, coal or oil we succeed in liberating only a small part of the energy in it. Also, we must go to all the work of cutting down the trees, mining the coal, or drilling oil wells and pumping the petroleum out of the ground.

In the past two or three years research has been undertaken to try to find ways to convert solar energy directly into useful energy. I have built a device to convert sunlight directly into electricity, which I call a parabolic mirror thermoelectric generator. It was built to illustrate the principle involved in this type of solar energy collector and also to get some idea of the efficiency which could be expected from a device of this type.

Several methods have been tried to harness the energy from the sun—probably the most popular of which is the solar battery which Bell Laboratories is experimenting with. Bell Laboratories hasn't, as far as I know, released any data or efficiencies on their solar battery so it isn't possible to discuss it in this paper. They may very well have the answer in their silicon crystals but we don't know yet.

*This paper received First Place Award at ASME Student Conference held at the University of Oklahoma, 1955.

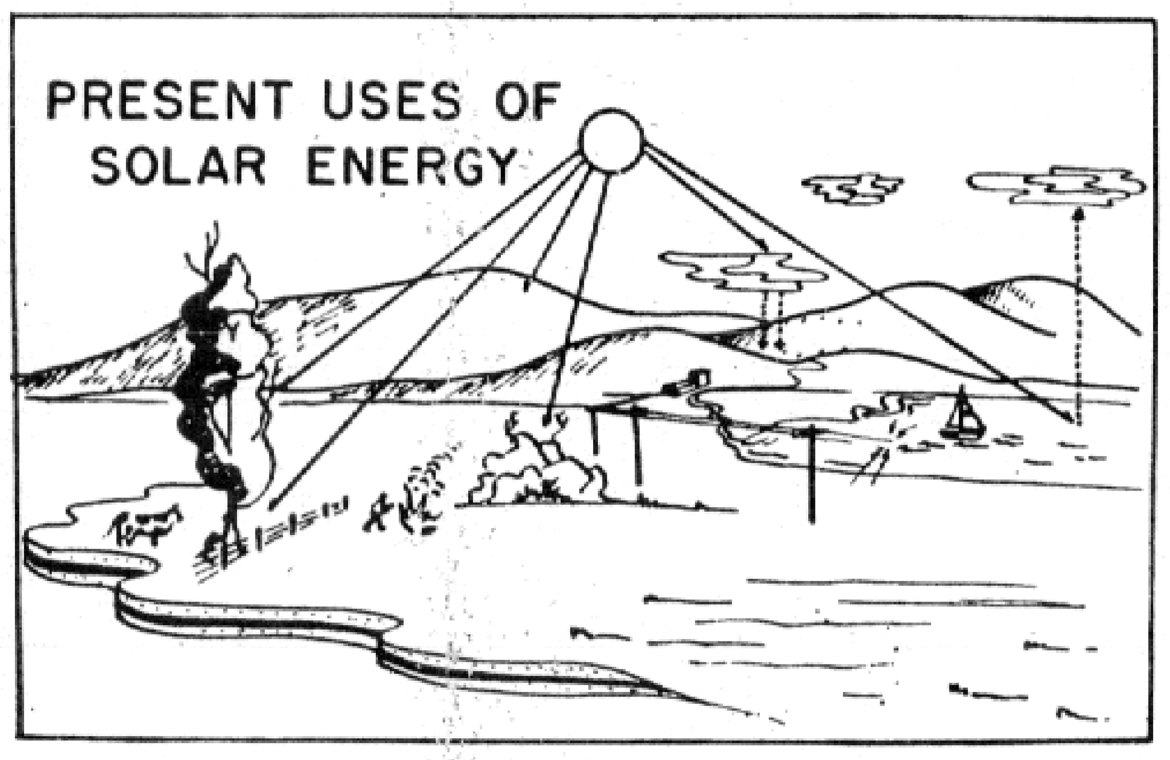


Fig. 1.

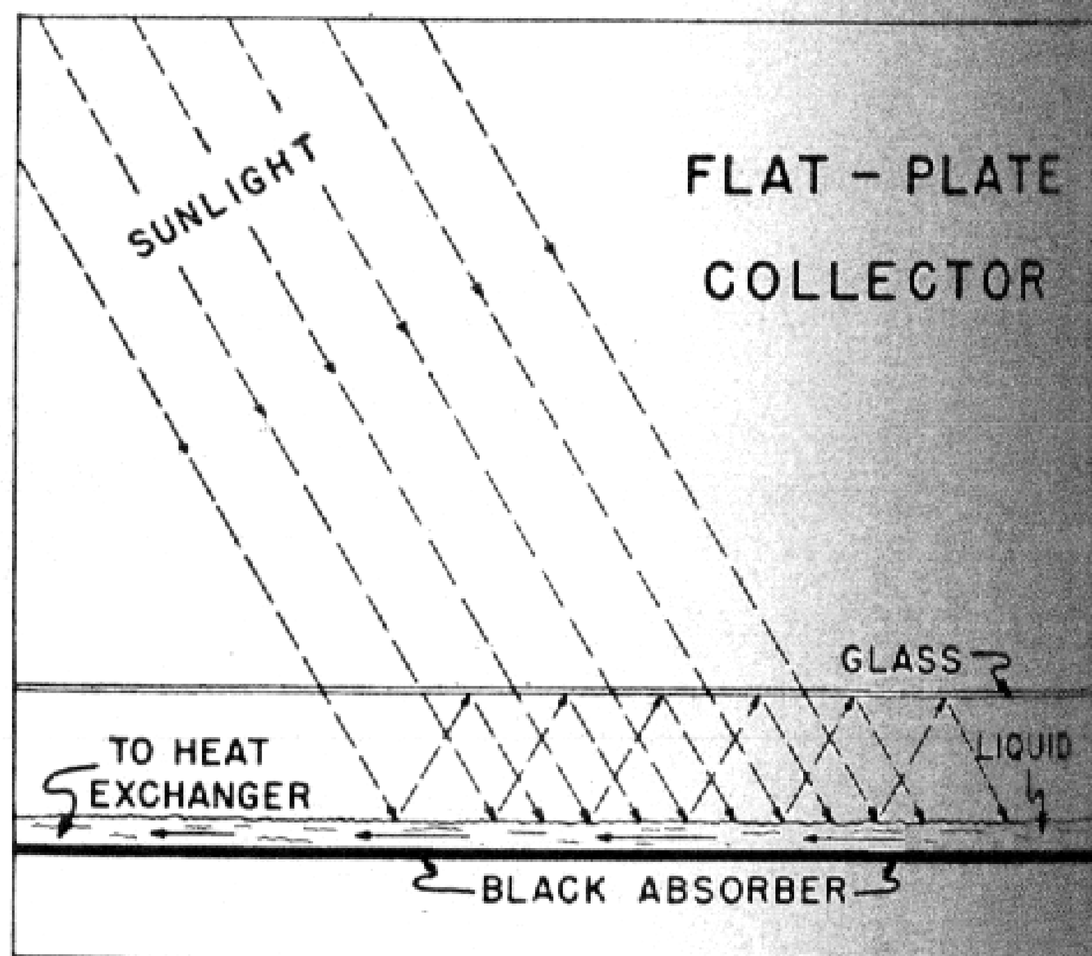


Fig. 2.

Another possible way of converting solar energy directly into useful energy is by means of a device known as a flat-plate collector. It consists of a black absorber covered with a glass plate which transmits short light rays but reflects long waves. Sunlight penetrates the glass and strikes the black surface. Most of the heat is absorbed here and the little that it reflected bounces back as long waves. These can't penetrate back through the glass so they bounce back to the bottom. The heat builds up quickly in the collector and can be used in one of two ways. One method, as shown in the figure, is to circulate a fluid between the black absorber and the glass plate to carry the heat away to a heat exchanger. Collectors of this type have been used to heat experimental homes.

Another way of using this type of collector is to place thermocouples in it instead of a fluid. Thus the solar energy is converted directly into electrical energy. At first thought we would think that this method would be impossible because of the very low voltages generated by thermocouples but Dr. Maria Telkes of New York University has done a lot of research on thermocouple materials and has developed some such materials which may make this type of application possible. In fact she has run some tests on just this type of collector and she has obtained some very interesting results.

Another possible way of converting solar energy directly into useful energy is by means of a mirror-type collector. In this device the sunlight strikes a parabolic reflector and is focused at the focal point of the reflector, giving a very high concentration of the solar energy.

Amazingly high temperatures have been produced by these reflectors. Convair has a 120 inch aluminum reflector which is used



to study the effect of high temperature on metals and ceramic materials. In their reflector they develop temperatures up to 8500°F. By comparison the temperature produced in an oxyacetylene torch is around 5800°F.

One way of using this type of collector as a power source is shown in figure 3. The high-boiling-point liquid circulates through the focal point of the reflector where it is heated by the high temperatures. The hot liquid is then circulated through a water boiler causing the water to boil and the resulting steam is used to drive a steam turbine. Dr. Charles G. Abbott of the Smithsonian Institute has done some experimental work on a unit of this type. Using the the device in this manner still requires the use of the steam cycle.

A way in which the parabolic mirror could be used to convert solar energy directly into electricity without the use of intermediate steps would be to place the hot junctions of a thermopile at the focal point of the reflector. This is the type of device which I constructed. This would have the advantage of doing away with the maintenance problems of the steam system. Also, there would be almost no depreciation since thermocouple materials do not wear out with use.

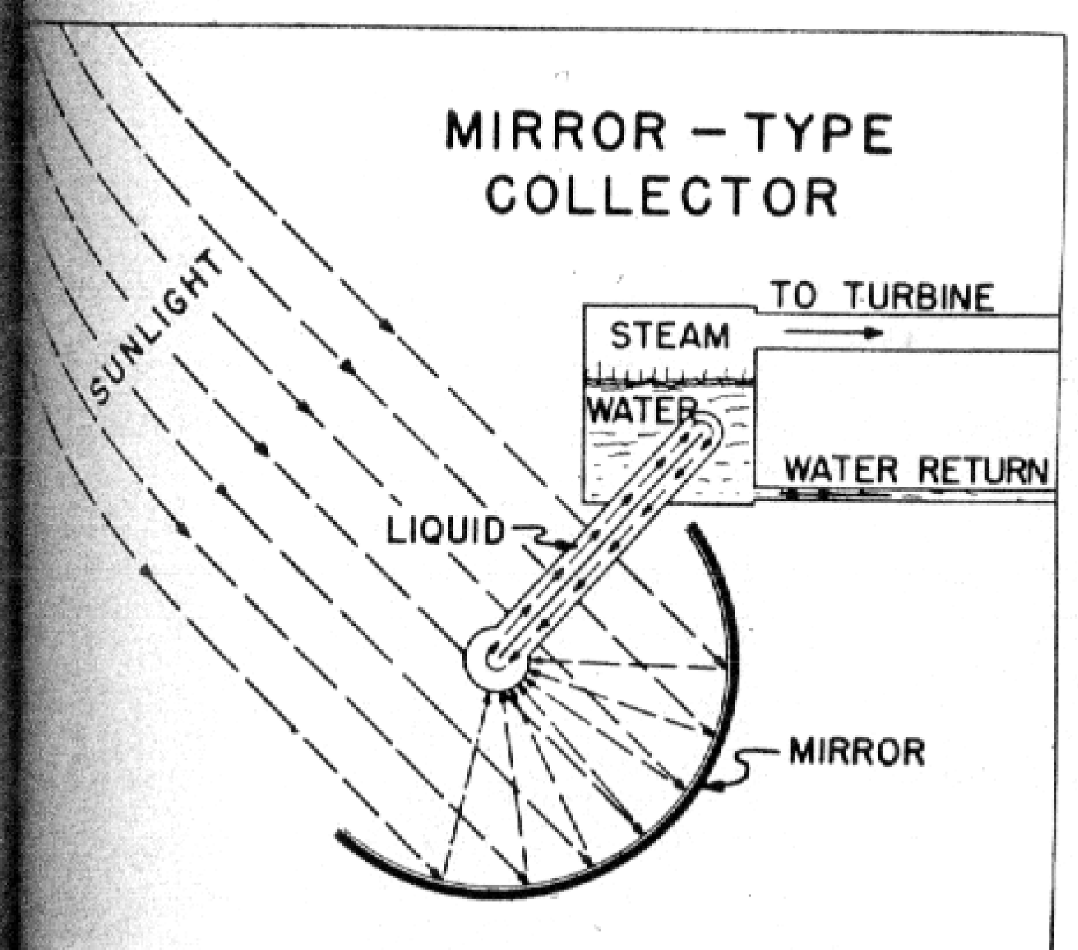


Fig. 3.

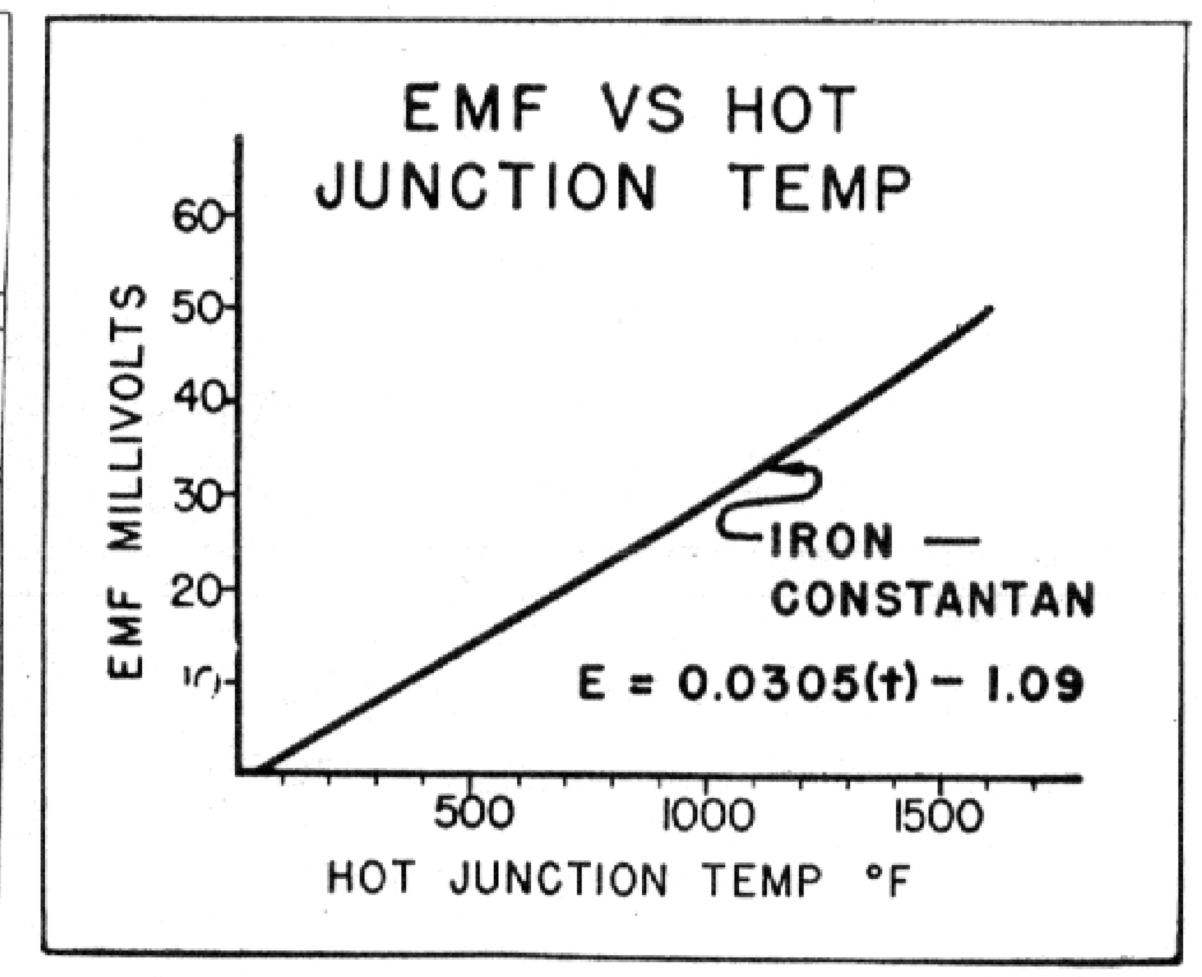


Fig. 4.

Shown in figure 4 is a characteristic curve of a thermocouple of which one conductor is made of iron and the other is of constantan. The slope of the curve is what is important because the slope is the generated emf per °F temperature difference between the hot and cold junctions.

Thermocouples, like batteries, may be connected with other thermocouples to increase either the generated voltage or the generated current. If they are connected in series the voltages add and if they

are connected in parallel the currents add. A group of thermocouples is called a thermopile.

For many years thermocouples have been used as temperature measuring devices but they haven't been considered as possible power sources. A lot of research has been done on thermocouple materials to increase the produced emf per degree temperature difference between the hot and cold junctions and the results are very encouraging.

In 1933 Mr. G. R. Fitterer experimented with thermocouples and found that a graphite-silicon carbide thermocouple had its own characteristic curve. The comparison with the iron-constantan curve is very striking because the extreme difference in the slopes of the curves can readily be seen. This means that the new thermocouple materials will produce a much higher emf for a given temperature difference. This was a very important step in the development of thermocouple materials but it wasn't the final step because in just the past two or three years, thermocouple materials have been developed which are even better.

Fig. 6.

Figure 6 is a picture of the device which I built and the equipment used in making the tests on it. I used the iron-constantan thermocouples because these materials were available in the small size 30 wire which was necessary. Then, using what I found with the iron-constantan thermocouple I could calculate what I would have gotten had the thermopile been made of graphite-silicon carbide thermocouples. The



reflector is the reflector from the headlight of a 1934 Ford. The thermopile consists of 20 thermocouples made of iron-constantan wire, all connected in series with the hot junctions at the focal point of the reflector.

This collector has some inherent characteristics which lower its efficiency. Because of its size, small wire was necessary and consequently the thermopile has a high internal resistance. This causes a large $I^2R$ loss and lowers the electrical output.

The reflector is very old and is of a mass production type which probably wasn't very accurately made. Truer parabolic mirrors with a higher reflectivity could be made and, therefore, somewhat higher efficiencies could be obtained. The day that the tests were made was a very windy day and no protection was made for the thermopile to protect it from the wind. It was noticed that the output varied a great deal with differences in wind velocity. This was because the wind tended to reduce the temperature of the hot junction. If it were protected from the wind by a glass cover over the mirror, the efficiencies would be increased.

With larger reflectors, much higher temperatures could be obtained at the focal point of the reflector and correspondingly higher efficiencies would result.

| TYPE | FLAT PLATE | PARABOLIC REFLECTOR | PARABOLIC REFLECTOR |
|---|---|---|---|
| MATERIAL | CHROMEL-CONSTANTAN | IRON-CONSTANTAN | GRAPHITE-SILICON CARBIDE |
| AREA (Sq. Ft.) | 0.388 | 0.267 | 0.267 |
| LOAD RESISTANCE (OHMS) | 0.088 | 44 | 4 |
| OPEN CIRCUIT EMF (Volts) | 0.086 | 0.317 | 2.900 |
| TEMPERATURE DIFFERENCE (Deg. F.) | 130 | 524 | 524 |

Fig. 7.

| TYPE | FLAT PLATE | PARABOLIC REFLECTOR | PARABOLIC REFLECTOR |
|---|---|---|---|
| MATERIAL | CHROMEL-CONSTANTAN | IRON-CONSTANTAN | GRAPHITE-SILICON CARBIDE |
| LOAD EMF (Volts) | 0.043 | 0.1587 | 1.45 |
| INCIDENT SOLAR ENERGY (Watts) | 31 | 17 3 | 17.3 |
| ELECTRICAL ENERGY OUTPUT (Watts) | 0.021 | 0.000573 | 0.53 |
| OVER-ALL EFFICIENCY (Per cent) | 0.068 | 0.003 | 3.06 |

Fig. 8.

In figure 7 and 8 I have compared the results of my tests with those found by Dr. Telkes with her flat-plate collector. She used 25 thermocouples in series made of chromel-constantan. She used these materials because they were available. From the results of her tests she could calculate what the results would be if the new alloys, which she has developed, were used.

Notice that with the parabolic reflector the emf is much higher than that obtained with the flat-plate, even though the area of the reflector was smaller. Notice, also, that the internal resistance of the flat-plate was much lower than that of the reflector.

The important thing is the overall efficiency. The efficiency is defined as the ratio of electrical energy output to the incident solar

energy which fell on the collector. In the case of the iron-constantan parabolic reflector the output is low because of the high internal resistance in the thermopile.

Indications are that if the graphite-silicon carbide thermopile were used instead of the iron-constantan in the parabolic reflector under the same conditions of this test, an efficiency of 3.06 per cent would be obtained. Dr. Telkes calculated that with her best thermocouple alloys she could obtain an efficiency of 1.05 per cent under the same conditions of her test which is shown here.

The efficiencies aren't significant in themselves because they are a measure of the output over input whereas the input is free. They are significant, however, when they are used as a comparison of different systems.

It is feasible that with a large, parabolic reflector type unit, efficiencies as high as 5 or 6 per cent would be fairly easy to obtain. Using a 5 per cent efficiency the size reflector that would be required for a 5000 KW generating capacity was calculated. The direct solar radiation on a clear day is around 300 BTU/ft$^2$ Hr. Using this as a basis the required reflector would have a diameter of 1205 ft. or 402 yards.

The efficiencies of flat-plate collectors could conceivably be raised to around 3 per cent if they were made very large and if some of the newly developed thermocouple materials were used. On this basis a 5000 KW gnerator would need to be 1375 ft. square or 445 yds. square.

An interesting comparison of several solar energy conversion devices which have been experimented with in the struggle to get more of the energy from the sun than nature gives us is shown in Figure 9.

Dr. Telkes has developed some new thermocouple materials and she calculates that with these new materials she can raise the efficiency, using the flat-plate collector, to 1.05 per cent. The "best materials" which I have listed under parabolic reflectors are newly developed alloys which are the best thermocouple materials known today. I am not familiar with their composition.

Nature has tied the knot of solar energy utilization mighty tight but I believe you will agree that these figures prove that it can be untied.

It is true that there are several problems which will have to be solved before we can use the energy from the sun. The sun only shines during the day so some sort of storage will be necessary if we are to use this energy during the night. The sunshine isn't predictable



## DATA

| TIME | LOAD VOLTAGE | LOAD RESISTANCE | INCIDENT SOLAR RADIATION | REFLECTOR SIZE |
|---|---|---|---|---|
| 3:45 | 158.70 MV. | 44 Ω | 1.0 GM CAL/MIN CM$^2$ | DIA = 7 IN. |

## CALCULATIONS

AREA OF REFLECTOR

$$A_{REF} = \frac{\pi D^2}{4} = \frac{\pi \left(\frac{7}{12}\right)^2}{4} = 0.267 \text{ FT}^2$$

INPUT (INCIDENT SOLAR RADIATION) = $W_{IN}$

$$W_{IN} = 1 \frac{\text{GM. CAL}}{\text{MIN. CM}^2} = 1 \times \frac{60 \times 930}{252} = 221.5 \frac{\text{BTU}}{\text{HR. FT}^2}$$

$$221.5 \frac{\text{BTU}}{\text{HR. FT}^2} \times 0.267 \text{ FT}^2 = 59.2 \frac{\text{BTU}}{\text{HR}}$$

$$W_{IN} = 59.2 \frac{\text{BTU}}{\text{HR}} = \frac{59.2}{3.413} = 17.3 \text{ WATTS}$$

OUTPUT = $W_{OUT}$

$$W_{OUT} = EI = \frac{E^2}{R} = \frac{(0.1587)^2}{44} = 0.000573 \text{ WATTS}$$

EFFICIENCY

$$EFF = \frac{W_{OUT}}{W_{IN}} = \frac{0.000573}{17.3} = 0.0000331 = 0.00331\ \%$$

HOT JUNCTION TEMP. °F ($t_{HOT}$)

$$E_{OPEN\ CIRCUIT} = 2 \times 158.7 = 317.4 \text{ VOLTS}$$

$$\frac{317.4 \text{ VOLTS}}{20 \text{ COUPLES}} = 15.87 \text{ MV/COUPLE}$$

$$E = 0.0305\, t_{HOT} - 1.09$$

$$t_{HOT} = \frac{15.87 + 1.09}{0.0305} = 556\ °F$$

ASSUMPTIONS —

$t_{HOT} = 556$ °F
$R_{INTERNAL} = R_{LOAD} = 4\ \Omega$
20 THERMOCOUPLES
$W_{IN} = 17.3$ WATTS

CALCULATIONS FOR GRAPHITE SILICON CARBIDE THERMOPILE

VOLTAGE PRODUCED

$$E = 0.1672\, t_{HOT} - 20.40$$
$$= 0.1672\,(556) - 20.40$$
$$= 93 - 20.40 = 72.60 \text{ MV./COUPLE}$$
$$= 72.60 \text{ MV./COUPLE} \times 20 \text{ COUPLE} = 1452 \text{ MV.} = 1.452 \text{ V.}$$

OUTPUT = $W_{OUT}$

$$W_{OUT} = \frac{E^2}{R} = \frac{(1.452)^2}{4} = \frac{2.12}{4} = 0.53 \text{ WATT}$$

EFFICIENCY

$$EFF = \frac{W_{OUT}}{W_{IN}} = \frac{0.53}{17.3} = 0.0306 = 3.06\ \%$$

and for this reason probably the first place to try a system of this type would be in India where the sun shines on an average of 300 days each year. Incidentally, there is probably more research going on in India to utilize solar energy than at any other place at the present time. In the case of the parabolic reflector type collector some device would be necessary to keep the reflector pointed directly at the sun at all times.

Yes, there are a lot of problems and much research and development would be necessary before it would be possible but I believe that, some day, we can take advantage of Old Sol's generous gift of energy.

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## HOWARD LEE CRUMLEY, XI CHAPTER, SECOND POLIO DEATH REPORTED IN ARLINGTON

Howard Lee Crumley III, Xi Chapter, of 3523 S. Utah St., Arlington, Va., died at District General Hospital to become the second polio fatality of the year in the Washington area.

Crumley, who was a senior at George Washington University, was placed in an iron lung Thursday night when his breathing was impaired. Hospital officials said cause of death was bulbar-spinal poliomyelitis.

Crumley, who was a senior at George Washington University, was scheduled to receive his bachelor of science degree in electrical engineering at midterm this winter. Just two weeks ago he began work as an electronics scientist at the National Bureau of Standards.

The first sign that he was stricken, his family said, was a series of severe headaches that began July 24. Last Tuesday the severity of the headaches forced him to leave his work at the National Bureau of Standards and return home.

On Wednesday a spinal test was taken at Arlington Hospital, which has no isolation ward. Crumley then was transferred to District General Hospital.

He was the fourth of six polio cases reported so far this year in Arlington. There were seven in Arlington at this time last year.

The 25-year-old youth was the son of Bessie F. Crumley. His father, Howard L. Crumley II, an engineer with the Virginia Electric and Power Co., died in 1951.

This fall he was to have married Miss Muriel Baldwin of 4700 16th St. NW. In addition to his mother, Crumley leaves one sister, Miss Susan Elizabeth Crumley, at home.



# WITH THE ALUMNI

### UNIVERSITY OF NEBRASKA

**Earle F. Cox, Alpha '41,** can be reached c/o USOM/E Alexandria, Egypt, Dept. of State, Washington 25, D. C., where he is a consulting engineer.

**Samuel C. Carrier,** Alpha '13, President of S. C. Carrier & Co., receives his mail at R. D. 2, Boonton, New Jersey.

**Dr. Hugh W. Gray,** Alpha '34, has been appointed director of the DuPont Company's new Film Department Research Laboratory, now under construction at the Experimental Station in Wilmington, Delaware.

**Durwood J. Hedgecock,** Alpha '36, has been appointed chief engineer of the Reynolds Metals Company, Richmond, Va.

**Richard A. Jay,** Alpha '39, manager of the Goodyear Lincoln plant since May 1948, will become assistant to R. P. DeYoung, vice president in charge of production at Akron, Ohio. He will specialize in industrial goods production.

**Nolan T. Jones,** Alpha '51, has sent in his Life subscription to the Pyramid. He is now residing at 318-A River St., West Newton 65, Mass.

**Louis E. Kuntz,** Alpha '51, reports his change of address to 2223 S. Dewey, Bartlesville, Okla. Mr. and Mrs. Kuntz are the parents of a son, David Robert, born March 21, 1955.

**Franklin O. Meier,** Alpha '35, has been named to the newly-created post of production manager at the Lincoln Steel Works, 315 West O. He will be connected with steel fabrication work of the plant. He was previously employed at the Gate City Steel in Omaha, and Missouri Portland Cement Company, in Kansas City, Mo.

**John J. Saunders,** Alpha '55, has been elected a member of the American Society of Civil Engineers. He resides at Creston, Ia.

**Ray L. Schacht,** Alpha '21, general manager of the Consumers Public Power District, Columbus, Nebraska, was named as one of 17 electric utilities executives who will advise the Atomic Energy Commission on licensing practices and policies.

**Norman Perry Shyken,** Alpha '55, has accepted employment as a mechanical engineer with the McDonnell Aircraft Corp. He resides at 6186 Pershing Avenue, St. Louis 12, Mo.

**Glenn E. Vest,** Alpha '54, was recently graduated from General Electric Company's A course, and is presently an engineer in the Development Dept., at Evendale, Ohio.

**Lee Smedley,** Alpha '28, watershed specialist for the southeast Nebraska area, S.C.S., U. S. D. A., has headquarters at Pawnee City, Nebraska.

**Fred J. Gunther,** Alpha '14, is vice-president of the Kansas City Power and Light Company. The same pressure is being exerted on this company as on many others in meeting the demand for power due to air conditioning and the tremendous number of room coolers that are being installed.

### UNIVERSITY OF PENNSYLVANIA

**Ens. Robert Rappaport,** Gamma '54, receives mail c/o USS Abbot, D. D. 629, c/o FPO, New York, N. Y.

### KANSAS STATE COLLEGE

**David G. Batchelder,** Epsilon '54, is presently engaged in research in Agricultural Engineering and farm machinery at Oklahoma A. & M. College. His work consists of research on corn planter improvement and grassland drill interseeding of temporary winter pastures in established native or tame pasture. His home is at 802 S. Monroe, Stillwater, Okla.

**Prof. James A. Bondurant,** Epsilon '50, has resigned his position as Assistant in Agricultural Engineering at the University of Nebraska, to work on a Doctorate in irrigation at the Utah State Agricultural College, Logan, Utah.

**Richard Lyman Clark,** Epsilon '49, has recently moved to 2808 W. 48th Terr., Kansas City 3, Kansas.

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